Load carriage and its force impact

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Introduction

Just as history records that military personnel have been carrying heavy loads for over two millennia (Orr, 2010), so too does it show their impact on military force sustainment and combat effectiveness. Around 800BC, the heavy loads carried by Assyrian soldiers reduced their mobility and led them to experiment continually with their shields in order to lighten their loads (Gabriel, 2002). Around 400BC, the long marches of Cyrus’ ‘infamous 10,000’, an army of Greek mercenaries accompanied by Xenophon, would have resulted in numerous stress fractures, torn ligaments, muscle damage, blisters and abrasions. While some of these injuries can be considered minor in the context of today’s available treatments, for the Cyrean soldier they could have been a matter of life or death as they hobbled to keep up with the moving army (Lee, 2007).

In World War 1, heavy loading of the foot soldier reduced the marching ability of the average soldier and was claimed to have altered the tactics of war (Lothian, 1921). The battles of Cambrai and Amiens provide examples in which forward movement, limited by physical exertion, was reduced to 9-12kms per day (Lothian, 1921). During the D-Day landings at Omaha Beach, American troops were so overburdened that their loads contributed to a number of deaths by drowning (Mayville, 1987). Carrying between 41.5 and 62.5 per cent of their body weight (Orr, 2010), most soldiers would have been seriously encumbered even before the added burdens of chest deep water, soft beach sands and heavy enemy fire.

In 1983, US soldiers assaulting an airhead in Grenada were so overloaded that one soldier described seeing ‘… all those guys sitting on the side of the road with IV tubes in them. There’s no way the guys could [have gone on]’ (Mayville, 1987, p. 26). In East Timor, the loads carried by Australian soldiers were thought to reduce their ability to pursue militia fleeing into the bush (Breen, 2000). More recently, in Afghanistan, the call has been made for light infantry that ‘can move further and faster on its feet than the enemy...’ (Lind, 2004, p. 14).

As in the past, the heavy loads currently being carried by many ADF members have the potential to impact adversely on force generation and sustainment, through manpower-reducing injuries as well as reducing the individual mobility and lethality of members in combat situations. This article commences with a review of contemporary knowledge regarding injuries likely to be sustained by members carrying heavy loads. It then progresses to examine the impact of load on individual mobility and lethality. Its aim is to highlight a number of ways to minimise the adverse effects of load carriage on force generation and force sustainment.
The burden of injury

Load carriage tasks frequently place increased stress on the muscles and skeleton of the carrier (Polcyn, Bensel, Harman & Obusek, 2000). This may lead to musculoskeletal injury, which in turn reduces available manpower and impacts on force generation and force sustainment. As an example of the impact on force generation, Pope et al (1999) found that over 50 per cent of Australian Army recruits discharged from recruit training were discharged as ‘medically unfit’, meaning the individual could not be fully rehabilitated and returned to active training within 12 weeks.

As an example of the impact of injury on force sustainment, a survey by Jennings et al (2008) identified that 80 per cent of US Army soldiers on modified work plans due to a musculoskeletal injury were unable to undertake load carriage activities, while 73 per cent were unable even to carry a rucksack. These findings are significant in highlighting the potential cost of musculoskeletal injuries on force generation and force sustainment.

When injury sites are aggregated, the lower limbs (knee, shank, ankle or foot) have been found to be the most frequent anatomical site of injury for military personnel (Jennings et al, 2008; Pope, 2007). When injuries on military load carriage marches were specifically reviewed, the lower limbs unsurprisingly also appear as the leading site of injury (Knapik, Reynolds & Harman, 2004; van Dijk, 2009). The ADF’s ‘Health Status Report’ of 2000 not only noted that the lower limbs were the most commonly injured body parts but also that they could be attributed with the highest rate of ‘working days lost’ and a rate more than double the next most commonly injured body part (Defence Health Services Branch, 2000).

While recreational hikers typically report sprains to the knees and ankles as their most frequent injuries (16.6%), followed by cuts (9.6%) and blisters (6.8%) (Lobb, 2004), the primary concern for military marching was found to be blisters (Bush, Brodine & Shaffer, 2000). While foot blistering may appear to be a relatively minor condition, complications such as infection may be more serious and have in the past led to occasional fatalities (Berkley et al, 1989). Furthermore, blisters have also been associated with causing other musculoskeletal soft tissue injuries, which may result through alteration of movement patterns as ‘hot spots’ develop (Bush et al, 2000).

Stress fractures are of particular concern for military personnel (Kelly, Jonson, Cohen & Shaffer, 2000; Pope, 1999). Thought to have been first described by a Prussian military doctor in 1855 (Brukner & Khan, 2001), stress fracture sites of military personnel typically include the pelvis, shin, heel and foot (Kelly et al, 2000; Milgrom et al, 1985; Pester & Smith, 1992; Pope et al, 1999). Pelvic stress fractures, which have long recovery and rehabilitation periods, have been found to occur more frequently in the female population (Kelly et al, 2000; Pope, 1999).

A plausible reason behind the higher female incidence rate for stress fractures could lie in gender-related height differences, which can lead to female members overstriding in order to march ‘in step’ with male members. With this in mind, a study by Pope (1999), which evaluated a multi-faceted intervention—that included reducing marching speed, allowing and encouraging female recruits to march at comfortable stride lengths and providing earlier awareness of upcoming obstacles—observed a 95 per cent relative decrease in pelvic stress fracture incidence. More generically, modification of training load (pace, volume, etc) has been found to decrease the incidence of stress fractures without necessarily impacting on physical development (Bennell, Matheson, Meeuwisse & Brukner, 1999; Pester & Smith, 1992).
One particularly debilitating injury associated with heavy load carriage activities is brachial plexus palsy (damage to the spinal cord nerves) (Corkill, Liberman & Taylor, 1980; Knapik et al, 2004; Makela, Ramstad, Mattila & Pihlajamaki, 2006). Also known as rucksack or backpack palsy, most reported cases occur in military personnel (Wilson, 1987), although cases have been reported in recreational backpackers (Corkill et al, 1980) and scouts (White, 1968). While the incidence of brachial plexus injuries may not be high when compared to other load carriage injuries, recovery can take up to several months (Bessen, Belcher & Franklin, 1987; Corkill et al, 1980; Makela et al, 2006; D. C. Reid, 1992; Wilson, 1987), with surgical intervention recommended following failure to recover strength and endurance after 24 months (Drye & Zachazewski, 1996).

With this in mind, Bessen et al (1987) found that only a third of the trainees in their study who suffered from a brachial plexus palsy were retained on active duty to continue training after a period of convalescence. Not only does this injury impact on force generation and sustainment, through long rehabilitation requirements, but its nature may impact directly on a member’s lethality. With weakness and paraesthesia (a sensation of tingling, pricking or numbness) being typical symptoms of brachial plexus neuropathies (Corkill et al, 1980; Knapik et al, 2004; Makela et al, 2006; D. C. Reid, 1992; Wilson, 1987), the ability of an individual to use their personal weapon could be impaired. This effect was observed in a study by Bessen et al (1987), where some military personnel presenting with brachial plexus neuropathies had difficulty even in carrying a rifle.

A study on backpacking paraesthesias, observing 280 backpackers carrying loads from 16.5-19.5kgs over 1,600kms of the Appalachian Trail, found a 34 per cent incidence of numbness or paresthesia, with digitalgia (numbness in the toes) being the most commonly identified type (Boulware, 2003). The second most common was meralgia, a paresthesia of the outer front aspect of the thigh (Boulware, 2003; Fargo & Konitzer, 2007). Recently Fargo and Konitzer (2007) reported on two case studies of coalition personnel serving in Iraq, both of whom suffered meralgia due to prolonged wearing of body armour. In these two studies, both members continued to present with symptoms a month after being diagnosed.

Injuries to the lower back are also common during or following load carriage tasks. In a study of military personnel completing a 20kms march with a 46kgs load, Knapik et al (1992) found lower back injuries to be second only to blisters. Unlike the members with blisters, however, over half of those who suffered a lower back injury were unable to complete the activity. When the biomechanical effects of load carriage on the human spine are taken into account—an increased trunk forward lean, increased lumbar compression and shear forces, changes to thoraco-pelvic rhythm and increased spinal torques (LaFiandra, Holt, Wagenaar & Obusek, 2002; LaFiandra et al, 2003; Polcyn et al, 2000)—then susceptibility to the recurrence of a lower back injury may mean these problems present on an ongoing or recurring basis.

Moreover, the incidence of musculoskeletal injury has been found to be higher during the early weeks of military training, when untrained recruits are adapting to an increase in exercise (Bush et al, 2000; Milgrom et al, 1985; Pester & Smith, 1992; Sheehan et al, 2003). Given that causal mechanisms for these injury patterns vary, Stein et al (1989) considered the onset of basic training to be the key causal injury factor, rather than the cumulative effect of marching ‘mileage’. With this in mind, however, Orr and Moorby (2006) found that Australian Army recruits marched on average more than 7kms per day at the commencement of basic
training; a distance that excluded physical training sessions and drill lessons. Similarly, a study by Knapik et al (2007), which included all activities completed during the day, found that US Army basic combat trainees covered an estimated 11kms per day. Thus the commencement of training itself can be linked with cumulative loading.

Trainee injury rates are typically highest during the weeks with the highest volume of physical training (Almeida, Williams, Shaffer, & Brodine, 1999). With basic military training for all three Services escalatory in its intensity, both the sudden commencement of training and the continuous and progressive volume of conditioning may combine to over-tax the musculoskeletal system to a point where any additional increases dramatically increase the chance of injury. Following basic training, this state of increased risk may then be transferred to the member’s trade training and even into their new units. Likewise, for members already in units which do not conduct sufficient physical training and load carriage conditioning, the sudden increase in training that may be experienced during pre-deployment training may predispose them to injury either during training or on deployment.

The impact of load carriage on mobility and lethality

Even if a member does not sustain an injury during load carriage, the loads carried can be expected to reduce their mobility and the mobility of their unit (LaFiandra et al, 2002; Mayville, 1987). Unsurprisingly, the amount of time taken by military personnel to cover a given distance has been found to increase with the load being carried (Harper, Knapik, & de Pontbriand, 1997; Johnson, Knapik, & Merullo, 1995; Knapik et al, 1997; Pandorf et al, 2002; Ricciardi, Deuster, & Talbot, 2008). As an example, one study found that the time to complete a 10kms march increased by 22.5 minutes (or 23 per cent) when loads were increased from 18 to 36kgs (Harper et al, 1997).

Similarly, the ability to negotiate obstacles has also been found to decrease as individual loads increase (Frykman, Harman, & Pandorf, 2000; Pandorf et al, 2002; Park et al, 2008; Polcyn et al, 2000). Of more concern is that while the absolute ability of members to negotiate some obstacles reduces as loads increase, the chance of tripping and falling also increases (Frykman et al, 2000; Park et al, 2008). When considering the confined spaces that soldiers and airmen on urban operations, or sailors on boarding parties, must negotiate while wearing body armour and carrying other loads, the lack of mobility and increased likelihood of falling and tripping could be life threatening. The same challenges are faced by Defence fire fighters when carrying self-contained breathing apparatus and moving through buildings or ships to fight fires.

Just as load weight impacts on obstacle negotiation, so too does the additional physical space taken up by the load. As an example, one study involving a crawl-through obstacle observed that completion times increase two-fold as the load increased from 14 to 27kgs, with the decreased crawl space and altered movement technique caused by the physical load space identified as the primary cause of the increase (Pandorf et al, 2002). Just as weight and size of the additional load impact on mobility, so too does load position. Additional loads carried in front of the body (as in a stores or cache carry, for example) have been found to cause the carriers to adopt a more cautious walking pattern, when negotiating obstacles, in order to avoid tripping (Perry et al, 2010).
Not only does load impact on mobility but several studies have found that load carriage tasks impact on a member’s lethality. With grip strength and hand steadiness essential for the accurate employment of personal weapons, the detrimental impact of load carriage on hand tremor and grip strength have been shown to impact on marksmanship (Knapik et al, 1991; Leyk et al, 2007; Leyk et al, 2006). Furthermore, as accurate weapon fire is associated with heart rate (Hendrick, Paradis, & Hornick, 2007), increased heart rates following a load carriage event (Datta et al, 1975) can be expected to impact adversely on weapon fire accuracy.

This has been corroborated by several studies, with performance found to decline following the completion of tasks involving load carriage of 34-61kgs (Knapik et al, 1997; Knapik et al, 1991) and stretcher carry tasks (Rice, Sharp, Tharion, & Williamson, 1999), with the assessments carried out in a variety of conditions and involving different firing positions. However, a study by Patterson et al (2005) did not find any significant changes in shooting performance when a range shoot was conducted approximately 30 minutes after a load carriage task, suggesting an adequate rest period is required for marksmanship to return to ‘base-line’ ability. Grenade-throwing ability has likewise been found to decrease following load carriage activities (Harman et al, 1999; Harper et al, 1997; Knapik et al, 1991). One study failed to find any impact; however, that may have related to technical skills and the higher levels of fitness of the special operations soldiers who participated in the study (Knapik et al, 1997).

When it comes to general duties, studies have found that when loaded with body armour (±10kgs) and performing simulated work, individuals performed at a reduced physical work capacity and showed increased physical fatigue (Ricciardi et al, 2008). Following a load carriage activity, even quite fit subjects—having carried loads of 30kgs over 20kms at a self-determined pace—demonstrated significant drops in aerobic capacity, indicating fatigue and a decreased ability to do work (Shoenfeld, Shapiro, Portugeeze, Modan, & Sohar, 1977). While these impacts may seem innocuous at first glance, fatigue can manifest in other areas, notably concentration, and lead to potentially life threatening incidents, such as the accidental discharge of personal weapons during or following a patrol or boarding party.

Perhaps of most significance are the cognitive impacts of load carriage. Apart from increased fatigue and muscle discomfort, a study found that alertness and feelings of well-being diminished during load carriage (Johnson et al, 1995). A more recent study observed a significant degradation of mental operations involved in executive processing (that is, performing goal-directed actions in an environment featuring complex stimuli) when military personnel carry a load of around 30 per cent of their body weight (May, Tomporowski, & Ferrara, 2009). The research findings suggest that their decision making processes were reduced in both speed and accuracy.

Perhaps of most concern are the findings of Mahoney, Hirsch, Hasselquist et al (2007), who found that when combat loads reach around 40kgs, vigilance also decreased. While vigilance to auditory stimuli decreased, significantly greater decreases were identified in relation to tactile and visual stimuli. This is important as it suggests that when burdened with heavy loads, members may fail to notice visually-observable cues, such as improvised explosive devices when on patrols, concealed weapons when conducting boarding parties or weakened structures when fire fighting.
What does this mean in practical terms? Whether it is foot patrols conducted by Army infantry soldiers or Air Force airfield defence guards, boarding parties conducted by Navy sailors, or fire fighting and special operational duties conducted by all three Services, the loads being carried can reduce the mobility and lethality of individuals and seriously impede their ability to carry out their duties.

**Minimising adverse effects**

In order to reduce injuries induced by load carriage, as well as minimising the impact of load carriage on the mobility and lethality of Defence personnel, the following measures are suggested.

**Physical conditioning for load carriage**

The need to condition military personnel to march with loads can be traced to antiquity (Orr, 2010). As an effective means of improving load carriage task performance and helping prevent load carriage injuries (Harman et al, 2008; Knapik et al, 2004), physical conditioning forms a vital part of force generation and force sustainment. This is only the case, however, if the training is conducted appropriately.

Orr, Pope, Johnston et al (2010) recommend that specific load carriage conditioning be conducted 2-4 times per month, a volume sufficient to provide a training stimulus but not so much as to cause a rapid overload. The intensity of the training sessions needs to be sufficient to elicit the desired training response and should progress to carrying loads similar to those required for military exercises and operational tasks. However, regardless of the level of conditioning, it is important to note that there is only a certain amount of load that the body can physically withstand and, as such, the loads should not be so excessive as to lead to injury.

Defence units which fail to maintain a load carriage conditioning program that meets these recommended training guidelines could be setting themselves up for failure. If load carriage fitness is poor, the amount of time needed to condition a member for operational tasks may exceed the time available during pre-deployment training. The result would be members who are either in a state of overtraining immediately prior to deployment (due to the sudden increase in load carriage duties during pre-deployment training) or under-trained for load carriage tasks on arrival in the area of operations.

**Lethality training**

Lethality training, including shooting and grenade-throwing from a variety of positions in a variety of conditions (both fresh and when fatigued), should be conducted regularly rather than once or twice a year to meet qualification requirements. With shooting accuracy expected to decrease following load carriage tasks, marksmanship skills need to be given greater attention (Mayville, 1987), rather than simply increasing ammunition allotments and hence load weight. These marksmanship skills should also be expanded to include firing serials following load carriage tasks in a variety of operational settings, as opposed to range practices conducted on pristine weapons ranges. The same would apply for grenade-throwing practices and training.
**Equipment control and integration**

Poor load carriage equipment integration may present as a major limiting factor in load carriage capacity (Drain, Orr, Billing, & Rudzki, 2010; Patterson et al, 2005). As an example, an assessment team in 2003, reviewing the load carriage practices of US personnel on operations in Afghanistan, identified issues with cinching the pack’s waist belt while wearing body armour. As pack waist belts are designed to transfer load on the shoulder and upper back, this system integration ‘disconnect’ potentially decreases the stability of the carrier’s walking pattern and increases their injury potential (S. A. Reid & Whiteside, 2000; Sharpe, Holt, Saltzman, & Wagenaar, 2008; Wilson, 1987).

In addition, efforts to improve load carriage equipment integration need to extend beyond the load carriage system to include additional items the individual may have to carry. Failure to do so may relegate the individual to a ‘Christmas tree on which we hang ornaments’ (Kreisher, 2009, p. 27), a concern graphically represented in a recent DSTO risk analysis of the ground based air defence trade (Attwells et al, 2007).

Military organisations, like ‘Gruntworks’ in the US (Kreisher, 2009), the ‘Personal Combat Equipment Team’ in the UK (Office of Ministry of Defence, 2010), and ‘Diggerworks’ in Australia (Army, 2011), have been created to address equipment integration concerns. However, for these organisations to be effective in both the short and long term, they need to be included in personnel equipment acquisitions and provided with continual support.

**Reducing the physical load**

Ways to reduce physical loads need to be explored with due consideration to other influencing factors. While reviewing the history of load carriage, Orr (2010) noted that changes in military tactics, logistics and technology have failed to make significant advances in reducing the physical load of military personnel. Modernisation programs, for example, can often have countervailing effects, where loads are reduced in one area only to be returned in another. As such, rather than improve the load carriage circumstance for military personnel, the load carrier is ‘overburdened with the weight of his technologies’ (Task Force Devil Combined Arms Assessment Team, circa 2003, p. 87).

New load carriage transport methods, like the multifunction utility/logistics equipment (MULE) (Bachkosky et al, 2007) or lower body exoskeleton (Eby, 2005), may be viable means of assisting military personnel to reduce their carried load or enhance their ability to carry a given load. However, these logistical aids will only be effective if available and if members are not simply supplied with greater loads due to greater carrying capacity. Thus, to effectively reduce the member’s physical load, the limited gains made by technological and logistic advancements should not be compromised by commanders seeing a means of supplying members with more equipment. Furthermore, methods to reduce the carried physical load should form part of a wider integrated approach to minimising the impact of load carriage rather than being relied on as the sole solution.
Summary

Load carriage tasks place physical stress on the carrier. This increase in stress may lead to injury, which in turn reduces available personnel and impacts on force generation and force sustainment. On operations, neuro-musculoskeletal injuries have the potential both to increase logistic workload and, as each individual member is effectively a weapons’ platform, to reduce unit fire power and thereby increase combat risk to other members of a unit. In addition, heavy load carriage has a negative impact on an individual’s mobility and lethality.

This reduction in combat task performance likewise increases the combat risk to the individual and their unit. To help mitigate these consequences, sufficient but not excessive load carriage conditioning training needs to be conducted and a greater focus needs to be placed on lethality training. The correct load carriage equipment for the task needs to be fitted, correctly worn and properly integrated. Finally, further means of reducing the carrier’s physical load need to be explored as part of a wider, integrated approach to minimising the impact of load carriage on the individual.

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